

DIATOMITE

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Production of diatomite in the United States decreased by about 3% to 624,000 metric tons (t), and its value decreased by almost 9% to \$159 million free on board (f.o.b.) plant in 2002 compared with 644,000 t valued at \$174 million f.o.b. plant in 2001 (table 1). The decline in production of diatomite in 2002 can be attributed in part to the slowdown in the growth of the U.S. economy and a drop in production from California, historically the main diatomite producing State. Despite the production decrease, the United States remained the world's largest producer and consumer of diatomite. Used primarily for filtration, major diatomite products were sold as various grades of calcined powders (table 2).

Description and Terminology

Diatomite is a chalk-like, soft, friable, earthy, very-fine-grained, siliceous sedimentary rock, usually light in color (white if pure, commonly buff to gray in situ, and rarely black). It is very finely porous, very low in density, and essentially chemically inert in most liquids and gases. Diatomaceous earth (often abbreviated as D.E.) is a common alternate name but more appropriate for the unconsolidated or less lithified sediment. The deposits result from an accumulation in oceans or fresh waters of the amorphous hydrous silica (opal, $\text{SiO}_2 \cdot n\text{H}_2\text{O}$) cell walls of dead diatoms, which are microscopic single-cell, often colonial aquatic plants (algae). The diatom cells contain an internal, elaborate siliceous skeleton consisting of two valves (frustules), which fit together much like a pill box. Fossilized diatom skeletal remains vary in size from less than 1 micrometer (μm) to more than 1 millimeter in diameter but are typically 10 to 200 μm across and have a broad variety of delicate, lacy, perforated shapes varying from spheres and cylinders to discs, ladders, feathers, and needles. Each deposit has characteristic assemblages that have been used to identify the source of material for forensic purposes. There are more than 10,000 species of extinct and living diatoms, some of which can live in ice and hot springs as well as marshes or even on moist bark, but they are most abundant in sunlit water—fresh or salt—that is constantly enriched with suitable nutrients and dissolved silica. Live cells are covered by a jelly, and masses appear as brownish water or films on stream bottoms. Extensive blooms of diatoms (algae) in coastal waters have caused severe pollution and anoxic conditions, and some species produce domoic acid, a nerve poison that, if ingested, quickly causes death in many animals (Eureka, 1998¹). Additionally, diatomite can form an excellent reservoir rock for hydrocarbons. The Belridge diatomite in the San Joaquin basin, California, is an oil-producing formation (Schlumberger, Inc., 2003§).

Diatomite also is known as kieselgur (a German name compounded from the words for flint and for an earthy sediment in water) and as tripolite after a diatomite occurrence near Tripoli, Libya. Tripolite is used in some government trade documents as the short name for the longer description of “siliceous fossil meals and similar siliceous earths...”. The short name is used more generally in the various tariff codes that cover diatomite (U.S. International Trade Commission, 2001§). An impure (up to 30% clay) Danish variety of diatomite is called moler.

Analysis of oven-dried samples of crude ore from many commercial operations typically shows 80% to 90% (in some cases 95%) silica (SiO_2) with smaller amounts of alumina (Al_2O_3 ; 2% to 4% attributed mostly to clay minerals) and hematite (Fe_2O_3 ; 0.5% to 2%), with an analytical ignition loss of 4% to 6%. Apparent oven-dry block density is 320 to 640 grams per liter (g/L) (compared with 1,000 g/L for water) with 80% to 90% voids. Diatomite ore contains from 10% to as much as 65% water (2% to 10% in the opaline structure). Dry crude rock can absorb from 1.5 to more than 3 times its weight in water. Dry powdered natural rock has an apparent density of 80 g/L to 250 g/L. The melting point of diatomite ranges from 1,000° C to 1,750° C (Durham, 1973; Breese, 1994, p. 398).

World reserves are estimated to be 800 million metric tons (Mt), which is about 400 times the current estimated world production of about 1.9 million metric tons per year (table 5). About 250 Mt of the estimated 800 Mt in world reserves is located in the United States (Antonides, 1999). The world reserve base was estimated by the U.S. Bureau of Mines in 1985 to be almost 2 billion metric tons (Meisinger, 1985). A resource estimate based just on the dimensions of the deposits near Lompoc, CA, suggests that collectively they could meet the world's current needs for centuries. Data on reserves, which are defined as being currently economic using proven mining practices among other qualifications, are not readily available and are difficult to calculate (U.S. Bureau of Mines and U.S. Geological Survey, 1980). In addition to considerable variation in physical and chemical properties between and even within deposits, the particular use and proximity to a market are major considerations.

Commercial deposits worldwide are reported to be mostly freshwater lake (lacustrine) deposits of Miocene to Pleistocene age, formed between 24 million and 10 thousand years ago. The reputed world's largest producing deposit that outcrops near Lompoc, however, is a huge marine deposit of Miocene age. Although known marine occurrences generally appear to be larger than the lacustrine deposits, a very large diatomite deposit reported in China appears to be lacustrine (Lu, 1998, p. 53). The oldest marine

¹References that include a section mark (§) are found in the Internet References Cited section.

occurrences are believed to be of Cretaceous age, about 138 million to 66 million years ago; any older occurrences presumably would have been changed into other forms of silica. Many deposits worldwide, especially of the older marine type, have been found in uplifted coastal areas exposed to some volcanic effects (such as in the Pacific rim from Chile to Japan). The oldest lacustrine deposits are believed to be of Eocene age, 55 million to 38 million years old. Lacustrine deposits, especially in mountainous localities, also often show some association with volcanic activity (such as the Pacific Northwest). However, there are lacustrine environments where diatomite deposits are presently forming in lowlands far removed from volcanic activity, such as Florida.

In antiquity, diatomite was used by the Greeks as an abrasive and in making lightweight building bricks and blocks. In A.D. 535, blocks of diatomite were used for the 30-meter-diameter dome of the church of St. Sophia in Constantinople (modern day Istanbul, Turkey) (Maurrasse, 1978). However, it only became of industrial interest in Western Europe in the mid-1800s. One of the first uses at that time was as cut blocks and bricks for heat-insulation. In the 1860s, pulverized diatomite became the preferred absorbent and stabilizer of nitroglycerine used by Alfred Nobel to make dynamite. The site of the first U.S. production of diatomite was in Maryland in 1884. By the late 1880s, the very pure, huge deposit near Lompoc became the focus of interest and has continued to dominate world markets. Diatomite is now used principally as a filter aid, but it has many other applications, such as an absorbent for industrial spills and for pet litter, a filler in a variety of products from paints to dry chemicals, an insulation material in sawn and molded shapes and loose granules, a mild abrasive in polishes, and a silica additive in cement and various other compounds.

Production

Recovery of diatomite from most deposits is by low-cost open pit mining because many occurrences are at or near the surface, and the topography allows for open pit mining. To remove overburden and excavate ore, different combinations of rippers, dozers, scrapers, front-end loaders, power shovels, and dump trucks are used. Outside the United States, however, underground mining is fairly common (such as in Chile, China, and France) owing to deposit form and depth and topographic and other constraints. Usually, room and pillar methods are used, often with equipment similar to that used in open pits, but the smallest mines are excavated with hand tools. Explosives are not normally needed at surface or underground mines because of the soft, friable nature of the rock. In Iceland, dredging is used to recover diatomaceous mud from the bottom of a Lake Myvatn. The ore is stockpiled at many mines in the open to segregate it by grade and to reduce the normally high moisture content before delivering it to the processing facility.

Diatomite usually is processed near the mine to reduce the cost of hauling up to 65% water, but the energy cost (electric power and fuel) at the site is an offsetting consideration. Processing typically involves a series of crushing, drying, size reduction, and calcining operations, using heated air for conveying and classifying within the plant. Commonly, spiked rolls and hammer mills are used for primary crushing to a size of 1.25 centimeters (0.5 inches), while limiting damage to the diatomite structure. With the heated air and multiple passes through special “milling” fans and air cyclones, further drying, size reduction, and classifying are accomplished. The cyclones not only classify for size but also remove undesirable components in the raw feed based on density differences. Size reduction aims at separating individual frustules without destroying their delicate structure. Fines, especially from baghouses used to remove particulates from the cyclone discharge waste or recycle air, are used mostly for filler-grade products, and the coarser bottom discharge particles are used for filter grades. In the latter stages of processing, calcining is normally done in rotary kilns to affect the physical and chemical changes previously mentioned. Plant operators take special precautions to overcome any free crystalline silica health hazards by containing dust within enclosures and requiring employees to use respirators. Although the generally high moisture in the ore reduces the free crystalline silica health hazards in mining areas, precautions are still taken. Wet scrubbers and fabric filters are the most commonly used devices to control emissions from diatomite dryers and calciners (U.S. Environmental Protection Agency, 1995§).

Production cost allocations were reported for the United States in 1983 as 10% mining, 60% processing, and 30% packing and shipping; a 1990 report stated energy costs were 25% to 30% of direct costs (Breese, 1994, p. 405). The proportion of the product that is calcined directly affects energy consumption.

The diatomite production data used to prepare table 1 were collected by a canvass of all known mine producers in the United States by the U.S. Geological Survey (USGS). The canvass received an 86% industry response rate for the tonnage and value sold or used, which historically has been used as a substitute for production. The canvass for 2002 covered 7 diatomite-producing companies with 13 separate mining areas and 12 processing facilities in California, Nevada, Oregon, and Washington. Two of these operations were reported as inactive, one of which reported a mine closure and reclamation. Major producers were Celite Corp. (Lompoc, CA, and Quincy, WA); Eagle-Picher Industries Inc. (Lovelock and Fernley, NV, and Vale, OR); and Grefco Minerals, Inc. (Burney, CA, and Mina, NV). Smaller producers were CR Minerals Corp. (Fernley, NV); Moltan Co. (Fernley, NV); and Oil-Dry Production Co. (Christmas Valley, OR). Nevada was the leading producing State, followed by California. The combined production of these two States accounted for about 77% of the U.S. production in 2002.

Consumption

Apparent domestic consumption (production sold or used based on the USGS survey plus imports minus exports using trade data furnished by the Department of Commerce; stock data are not available) of diatomite in 2002 was about 497,000 t, down slightly from 498,000 t in 2001.

According to data from the USGS canvass, the total domestic and export quantity of filter-grade diatomite sold or used by U.S. producers was 423,000 t in 2002, down from 442,000 t in 2001. For absorbents, the second largest category, 89,000 t was consumed,

down slightly from 90,000 t in 2001. Filler and insulation applications remained unchanged from 2001 and accounted for about 76,000 t and 18,000 t, respectively. Other consumption applications also remained unchanged in 2002 at 18,000 t, special product sales and cement manufacturing constituting the majority of that amount (table 2). Comparing 2002 data with 1997 data for percentage of total use, filter use decreased; filler use, insulation, and absorbents remained the same; and other uses (mostly special product sales and cement manufacture) increased.

Commercial diatomite products provide fine-sized, irregular-shaped porous noncaking particles that have a large surface area and high liquid absorption capacity. They are relatively inert chemically, have a low refractive index, are mildly abrasive, have low thermal conductivity with a reasonably high fusion point, can be slightly pozzolanic, are very high in silica, and can be produced and delivered at a cost consistent with customer applications. Sawn shapes, which continue to account for a significant part of world diatomite production, have long been used as lightweight building material most recently in 20th century China and for primarily thermal insulation (especially the high-clay-containing Danish moler). Dried natural products and calcined products are used in the aforementioned applications. Particulate products are more widely used and can be tailored to fit desired uses by blending various grades of calcined and natural material. The major use, in a great variety of grades, is as a filtration medium for beverages (especially beer and wine), sugar and sweetener liquors, oils and fats, petroleum and chemical processing (including waste drycleaning fluids), pharmaceuticals, and water (potable, industrial process, waste, and swimming pool). Two large and growing applications are as an absorbent for industrial spills (oil and toxic liquids) and for pet litter. Another important broad category of use is as a filler, often serving a dual purpose, such as an extender and flattening agent in paints and coatings, a bulking and anticaking agent in granular materials, a multieffect component in plastics (including preventing films from sticking), and an extender/absorbent carrier for dry pesticides, pharmaceuticals, catalysts, and other chemicals. Significant other uses are as an insulation material in bulk (loose) and in molded forms, other insulation products that include calcium silicate as a component, and as a silica additive in various compounds, including mortar and portland cement where it is used also for its pozzolanic properties. Worldwide use, including moler, was estimated in 1993 to be almost 45% for filtration, more than 25% for fillers, 17% for insulation, and about 11% for absorption and other applications (Roskill Information Services Ltd., 1994, p. 3).

Commercial diatomite products are offered in a great variety of grades. Principal factors are the size, shape, overall arrangement and proportions of the various types of frustules (factors that affect filtration rate, product clarity, and absorption capacity), and content of silica and various impurities, such as certain minerals and chemicals (especially the form of iron, a major impurity), clay, sand, and organics. There are a number of additional specialized application specifications, such as brightness/whiteness and abrasive hardness. Reduced free crystalline silica content, although normally low, also is required by some environmental regulations, particularly for calcined products. A major influence on the grade is the extent of processing within the following three broad classifications: naturally milled and dried; plain ("straight") calcined (to 1,000° C); and flux-calcined (to 1,200° C) with the addition of up to 10% of sodium compounds, such as soda ash, salt, or sodium hydroxide). Calcining removes organics, increases filtration rate (surface area is reduced by fusing more delicate structures of particles and sintering them into small clusters resulting in larger particle size and increased pore size), oxidizes iron (changing the buff to gray colors common in crude ore feed to pink or white), increases specific gravity, and increases particle hardness, but also disadvantageously produces free silica. Flux-calcining significantly affects the physical and chemical properties and makes a white product. Most filter grades are calcined.

Prices

The calculated weighted average unit value of diatomite sold or used by U.S. producers during 2002, using USGS survey data, was almost \$255 per metric ton f.o.b plant, a decrease compared with about \$271 per ton in 2001 (table 3). The average values per ton for almost all end uses in 2002 were down from the 2001 values. The exception was for insulation use, which remained the same. Comparing unit values in 2002 with those in 1997, in current [2002] dollars, the calculated weighted average unit value has increased by \$11 per ton from \$244 per ton. The filter-grade product price in 2002 was \$33 per ton less than in 1997. The filler-grade unit value in 2002 was \$31 per ton more than the \$279 per ton price in 1997. Data on other grades are insufficient for accurate comparisons, although unit values for insulation grades appear to have decreased.

Foreign Trade

Export and import data presented herein are from the U.S. Census Bureau and are of limited accuracy owing to producer-reported inconsistencies as well as lack of detail for the various materials specified in the 2002 Harmonized Tariff Schedule of the United States (HTS) issued by the U.S. International Trade Commission (2001§).

Exports of diatomite from the United States in 2002, according to the census data, were about 128,000 t, which accounted for about 21% of total domestic production sold or used as shown in the USGS survey, but were 20,000 t less than 2001 exports (table 4). Products were exported to 83 countries according to the U.S. Census Bureau data. The main export markets were the Netherlands (21,400 t), Canada (17,700 t), Belgium (9,920 t), Japan (8,700 t), Australia (7,800 t), and Germany (6,550 t), making up slightly more than 56% of the total exports reported. Based on the available data, the average unit value of exported diatomite was \$316 per ton free alongside ship (f.a.s.), compared with \$324 per ton in 2001 and \$305 per ton in 1997. Because the data may not include all the higher value material, as discussed above, actual average unit values may be higher.

Industry information indicates that actual total exports of diatomite products can be estimated to be a minimum of 300,000 metric tons per year (t/yr), which is about 48% of domestic mine production sold or used in 2002 according to the USGS survey. Industry

sources suggest that 75% or more of exports are flux-calcined, with the balance being mostly natural or straight-calcined grades and only a small portion being material described in headings 6806 and 6901 of the HTS.

Import data available for diatomite show 528 t coming from six countries. In descending order, Italy provided 35%, followed by Mexico with 21%, with the remainder coming from Australia, France, Spain, and Canada.

World Review

Chinese diatomite production increased, and Japanese production remained essentially the same in 2002, when compared with the previous year. For 2002, world output was estimated to be 1.92 Mt, which was a minor decrease compared with that of 2001 (table 5). Major producers in 2002 were the United States at 32%, followed by China at 19%, Japan with 10%, Denmark with about 10% (all molar products), Mexico with about 4%, and some countries of the Commonwealth of Independent States with 4%.

Outlook

Industry representatives expect the next 5 years to be similar to the past 5 years. Increased energy costs and possible global overcapacity, however, may represent impediments to future expansion. The past encroachments into filter applications by more advanced technology (ceramic, polymeric, and carbon membranes) apparently are not of major concern to producers, possibly because of cost factors. Disposal of diatomite waste, however, is a problem not fully resolved by recycling. Emerging markets for diatomite include use in biotechnology and pharmaceuticals and as a nontoxic insecticide (Crossley, 2000, p. 135). The problem of free crystalline silica associated with diatomite, particularly when calcined, continues to be of concern.

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TABLE 1
DIATOMITE SOLD OR USED, BY PRODUCERS IN THE
UNITED STATES¹

(Thousand metric tons and thousand dollars)

	2001	2002
Domestic production (sales)	644	624
Value	\$174,000	\$159,000

¹Data are rounded to no more than three significant digits.

TABLE 2
DIATOMITE SOLD OR USED, BY MAJOR USE¹

(Percentage of U.S. production by metric tons)

	2001	2002
Absorbents	14	14
Fillers	11	12
Filtration	69	68
Insulation	3	3
Other ²	3	3

¹Includes exports.

²Includes silicate admixtures (especially for cement) and unspecified uses.

TABLE 3
AVERAGE VALUE PER METRIC TON OF
DIATOMITE, BY MAJOR USE¹

	2001	2002
Absorbents	\$173.36	\$118.94
Fillers	336.11	328.51
Filtration	250.23	245.56
Insulation	35.71	35.71
Other ²	1,149.95	1,072.42
Weighted average	270.74	254.58

¹Based on unrounded data.

²Includes absorbents and silicate admixtures.

TABLE 4
U.S. EXPORTS OF DIATOMITE^{1, 2}

(Thousand metric tons and thousand dollars)

Year	Quantity	Value ³
2001	148	\$47,800
2002	128	40,400

¹Harmonized Tariff System (HTS) heading 2512.00.0000, natural and straight-calcined grades, but in practice probably includes an undetermined quantity of flux-calcined product HTS heading 3806.90.2000.

²Data are rounded to no more than three significant digits.

³Free alongside ship U.S. customs value.

Source: U.S. Census Bureau.

TABLE 5
DIATOMITE: WORLD PRODUCTION, BY COUNTRY^{1,2}

(Thousand metric tons)

Country	1998	1999	2000	2001	2002 ^c
Algeria	2	3	3 ^e	3 ^e	3
Argentina	25	43	35 ^e	35 ^e	30
Australia ^e	20	20	20	20	20
Brazil, marketable ^e	14	14	14	14	14
Chile	15	14	13	23 ^r	23
China ^e	335	340	350	350	370
Colombia ^e	4	4	4	4	4
Costa Rica	16 ^r	18 ^r	35 ^r	26 ^r	26
Czech Republic	35	37	34 ^r	35	35
Denmark ^{e,3}	185	185	185	185	185
France ^e	80	80	75	75	75
Iceland ^e	26	28 ⁴	28 ⁴	28	28
Iran ^{e,5}	1	4 ⁴	5	5	5
Italy ^e	25	25	25	25	25
Japan ^e	190	190	190	190	190
Kenya	(6)	4	4	4 ^e	4
Korea, Republic of	37	30	34	28 ^r	30
Macedonia ^e	5	65	5	5	5
Mexico	67	65	96	69 ^r	70
Peru ^e	35	35	35	35	35
Poland	2	1	1	1	1
Portugal	2	2	2	2	2
Romania	35 ^r	12 ^r	9 ^r	7 ^r	6
Soviet Union, former ^{e,7}	80	80	80	80	80
Spain ^{e,8}	36	36	35	35	35
Thailand	--	2	(6)	(6) ^e	(6)
United States ⁹	725	747	677	644	624 ⁴
Total	2,000 ^r	2,020 ^r	1,990 ^r	1,930 ^r	1,920

^cEstimated. ^rRevised. -- Zero

¹World totals, U.S. data, and estimated data are rounded to no more than three significant digits; may not add to totals shown. Purity and moisture content are generally not reported or estimated.

²Table includes data through April 4, 2003.

³Data represent "extracted moler," calculated as reported cubic meters times 1.5. Contains about 30% clay.

⁴Reported figure.

⁵Data are for Iranian years beginning March 21 of that stated.

⁶Less than 1/2 unit.

⁷The Soviet Union was dissolved in December 1991, but information is inadequate for formulation of reliable estimates for individual countries.

⁸Includes tripoli.

⁹Sold or used by producers.